Stability and Stiffness of Asphaltic Concrete Incorporating Waste Cooking Oil

Ramadhansyah Putra Jaya, Khairil Azman Masri, Haryati Awang, Mohamad Idris Ali, Noram Irwan Ramli, Wan Nur Aifa Wan Azahar, Ekarizan Shaffie, Haryati Yaacob, Muhammad Naqiuddin Mohd Warid, Ichwana Ramli

***Abstract*: The application of waste material is extensively used as a partial replacement to produce a new asphalt binder with the improvement of binder performance. However, limited information is available on the use of waste cooking oil (WCO) in hot mix asphalt. In this regard, the main objective of this research is to study the influences of WCO as a supplementary binder on the Marshall Stability properties of asphaltic concrete. The properties investigated are stability, stiffness and flow. Results show that the treated WCO proved better strength performance as compared to the other asphalt mixture. It also found that the modified mixtures incorporating untreated and treated WCO increased the tendency for deformation exposure as compared to the control mixture. Generally, Marshall Stability result for treated WCO mixture was improved from untreated WCO mixture and exceeded the control mixture performance.**

Key Words: waste cooking oil (WCO).

I. INTRODUCTION

Waste materials are widely used as a constituent part of a substitution element in the production of modified asphalt binder to modify conventional binder properties [1]. This waste material is obtained from household, commercial, and industrial by-products [2]. These waste products have a discreet and specific property, which enable them to be an additive or a modifier element [3]. These additives come in liquid and powder forms that are desirable for modifying and upgrading construction material properties. To prevent pavement distress and minimise the total maintenance work cost, the bituminous layer should be strengthened with high-quality recycled waste materials to improve its mechanical properties regarding permanent deformation resistance, fatigue and so on. The application of waste and a recycled product has fulfilled the sustainable development requirement so that a green highway can also be achieved [4].

Bitumen is recognised as an essential coating material in bituminous pavements composition apart from the aggregates skeleton for pavement construction. In hot mix asphalt structure, the binders' functions as an adhesive agent for the coating process and bind the aggregate particles together [5]. The asphalt binder exhibits insufficient properties for road construction and necessary to be modified with several additives [6]. Currently, many notable studies are being conducted worldwide to explore valuable resources from waste materials as a modifier for asphalt binder modification. In recent times, a wide range of oil-based modifications have been introduced, especially involving WCO. This oil source has recently gained widespread attention because of its satisfactory achievement as potential waste material to enhance the physical and rheological performance of modified binder. Most of the previous studies have concentrated on the modified binder incorporated with WCO [5][7]. However, none of the researchers emphasized the basic parameter affecting oil modification [8]. Besides, this parameter is not clearly explained since the bitumen modification with WCO is still in the empirical stage.

II. MATERIAL AND METHODS

A. Aggregate and Gradation

Crushed granite aggregates were used throughout the study. Aggregate material tests were carried out based on the American Society for Testing and Materials (ASTM) and British European (BS EN) standard. It was found that the coarse and fine aggregates had a specific gravity of 2.70 g/cm3, as well as water absorption rates of 0.65% and 1.05%, respectively. Also, granite aggregates have 14% of aggregate impact value and 17% crushing value. On the other hand, aggregate gradation for asphalt mixtures was obtained from Malaysian Public Works [9] as given in Table I.

Revised Manuscript Received on March 20, 2019.

Ramadhansyah Putra Jaya, Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang, Pahang, Malaysia.

Khairil Azman Masri, Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang, Pahang, Malaysia.

Haryati Awang, Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang, Pahang, Malaysia.

Mohamad Idris Ali, Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang, Pahang, Malaysia.

Noram Irwan Ramli, Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang, Pahang, Malaysia.

Wan Nur Aifa Wan Azahar, Kulliyyah of Engineering, Civil Engineering Department, International Islamic University Malaysia, Kuala Lumpur, Malaysia.

Ekarizan Shaffie, Institute for Infrastructure Engineering and Sustainability Management (IIESM), Universiti Teknologi MARA, Selangor, Malaysia.

Haryati Yaacob, Faculty of Engineering, School of Civil Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia.

Muhammad Naqiuddin Mohd Warid, Faculty of Engineering, School of Civil Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia.

Ichwana Ramli, Faculty of Agricultural, Syiah Kuala of University, Banda Aceh, Indonesia.

Table I. Aggregate Gradation of Asphalt Mix [9]

Sieve size (mm)	Lower limit	Upper Limit
20	100	100
14	90	100
10	76	86
5	50	62
3.35	40	54
1.18	18	34
0.425	12	24
0.15	6	14
0.075	4	8

B. Bitumen and WCO

In preparing the Marshall Stability test, bitumen with penetration grade of 60/70 was used. The physical characteristics of this bitumen were summarized in Table II. On the other hand, the raw sample of WCO was collected from a restaurant and was filtered first to remove food, dirt, and impurities. Single-step transesterification reaction was used to reduce the presence of a high acid value in the WCO. After the treatment process was completed, the original of the WCO (untreated) changed into treated WCO.

Table II. Properties of the 60/70 bitumen

Parameters	Values
Penetration at 25°C (d-mm)	65.0
Softening point (°C)	52.0
Specific Gravity (g/cm^3)	1.03
Viscosity at 135°C (cP)	500

C. Marshall Stability Test

A 5% of WCO by weight of binder was selected and replaced into the modified binder before being mixed with the aggregates in the asphalt mixture. Five different content of bitumen, i.e. 4%, 4.5%, 5%, 5.5% and 6% was chosen as required by the Malaysia public work department for asphaltic concrete 14 (AC14). On the other hand, asphalt concrete samples were prepared by 101.6 mm inner diameter steel Marshall mould. The temperature of the samples was 60°C and the load applied was at a rate of 50 mm per minute. The test was carried out in compliance with ASTM D6927-15 using the Marshall Stability testing machine [10].

III. Result and Discussion

A. Stability

The Marshall Stability performance test for all asphalt mixtures is shown in Fig 1. It can be clearly observed that a similar trend of stability was recorded by untreated and treated WCO mixture, in which the stability was increased at 4% - 4.5% before further consistently decreased from 5% - 6% of bitumen content. The vital factor that attributed to the highest stability properties was the polarity group between the modified binder with treated WCO and the surface of the aggregates. In principle, the polar group has high affinity to another polar group and vice versa. The polar group similarity between aggregates and the modified binder, that contained treated WCO, caused these materials to attract each other to form a strong bond. The bond eventually increased the binder adhesiveness towards the aggregate in the bituminous mixture. Therefore, the stability of the asphalt mixture was enhanced with treated WCO.

In contrast, the stability in the control mixture depicted the different trend, wherein the stability results initially increased from 4% - 5% of bitumen content. It then further decreased with increasing bitumen content at 5.5% - 6%. In comparison between all the mixes, the increment trend of stability was recorded from untreated WCO, control and treated WCO mixtures. Based on Fig 1, untreated WCO mixture stability was found to range from 1056 – 1260 kg, which was recorded lower as compared to the control mixture (1427 – 1240 kg) at 6% - 4% of bitumen content. Similar to trends with the control mixture, the higher stability exhibited by treated WCO mixture, which recorded from 1413 - 1701 kg for 6% - 4% of bitumen content, respectively as compared to the untreated WCO mixture. It can be noticed that the treated WCO achieved the highest stability especially at 4.5% and the untreated WCO mixture recorded 5% of bitumen content followed by a control mixture and the lowest stability. Similarly, [11] was found that the modified mixture incorporating oil shale recorded higher Marshall Stability result as compared to the control mixture. By referring to the pattern result, it can be observed that all the asphalt mixtures recorded the least stability at 6%. This was because the addition bitumen at higher bitumen content produced thicker films around individual aggregates, which in turn displaced and pushed apart between the contacted aggregate skeleton. This may result in a loss of one to one contact points of the aggregate particles as the voids were filled with the increasing bitumen content. This was the reason why the stability started to decrease as the bitumen content was further increased beyond a certain value.

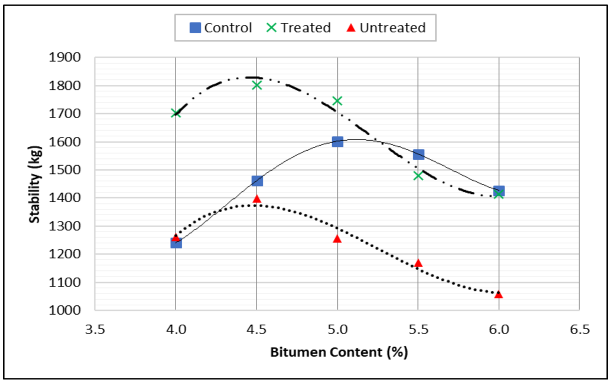

Fig 1 Stability of asphaltic concrete containing untreated and treated WCO

B. Flow

The results of flow for control, untreated WCO and treated WCO mixtures are illustrated in Fig 2. The flow was consistently increased parallel to a higher addition of bitumen content from 4% - 6%. The higher the treated WCO was added into the mixture, the higher was the existed deformation rate. This performance was affected by the fluidity factor, wherein the lubrication effect possessed in treated WCO had caused the sliding potential between the aggregates particle as the modified binder with treated WCO had difficulties to hold and bind with the aggregates. However, sufficient bitumen content was required at an optimum dosage to enhance the resistance of flow deformation in the asphalt mixture. Based on Fig 2, the flow of control mixture was represented in a range of 2 - 4.69 mm, which was recorded lower as compared to untreated WCO mixture. The flow results for untreated WCO mixture attained in this study were recorded at 2.63 to 4.73 mm for 4% - 6% of bitumen content, respectively. Meanwhile, the flow for treated WCO mixture was presented as 2.43 mm for 4% and 3.19 mm for 4.5% bitumen content and was recorded lower as compared to the untreated WCO mixture. Surprisingly, at 5% - 6% of bitumen content the increment of flow for treated WCO mixture were noticed to be represented at 3.58 mm, 4.55 mm and 6.44 mm, which were recorded noticeably higher as compared to untreated WCO mixture. In comparison between all the mixes, the control mixture exhibited the lowest flow as compared to the modified mixture with untreated and treated WCO. However, [12] reported different results with this study found, wherein the modified mixture with used cylinder oil, achieved the lowest flow as compared to the control mixture. The flow properties represent the deformation rate potential in the bituminous mixture. High flow indicated that the high tendency in pavement mixture easily exposed the deformation. It can be said that the alteration of deformation rate was low at minimum bitumen content but rapidly increased as the maximum bitumen content was reached.

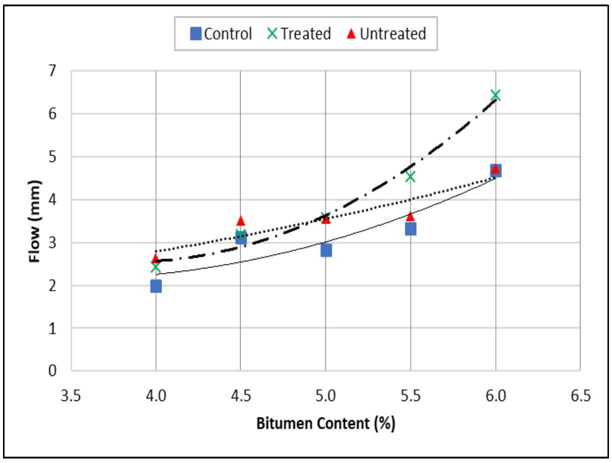

Fig 2 The flow of asphaltic concrete containing untreated and treated WCO

C. Stiffness

The stiffness of asphaltic concrete containing untreated and treated WCO was decreased as the bitumen content increased from 4% - 6% as presented in Fig 3. However, inconsistent stiffness result was observed in the control mixture wherein stiffness was initially decreased at 4% - 4.5%, increased at 5% before further decreased with higher bitumen content at 5.5% - 6%. Generally, the increasing trends of stiffness results were recorded from untreated WCO, treated WCO and control mixtures. The high stiffness achieved by control and treated WCO mixtures attributed the similar polarity group in which it enhanced the internal chemical bonding thus increased the adhesion performance with the aggregates. The high adhesion property produced the hard and stiff mixes, thereby improved the strength of the asphalt mixture. It was expected that the high stiffness possessed in control and treated WCO mixtures increased the rutting resistance performance, hence led to the low permanent deformation exposure. As a conclusion, the stiffness was improved in control and treated WCO mixtures, while the lowest stiffness in the untreated WCO mixture indicated that the low rutting resistance performance thereby tends to increase the rut depth.

Based on Fig 3, the stiffness attained from this test was ranged between 620 – 304.5 kg/mm for control mixture, 479.2 – 223.5 kg/mm for untreated WCO mixture, and 700.4 – 219.5 kg/mm for treated WCO mixture for 4% - 6% of bitumen content. This implied that the control mixture exhibited the highest stiffness followed by treated WCO mixture and untreated WCO achieved the lowest stiffness. The stiffness of the mixture obtained in the test was affected by the stability and flow. The higher stability with the lower flow was desirable for high stiffness performance. The lowest stiffness was achieved by untreated WCO mixture as compared to the other mixture due to the lowest stability with high flow rate obtained, especially for 4% - 4.5% of bitumen content. On the other hand, the decrement of stiffness performance implied that the untreated WCO mixture had low rutting resistance thereby indicated the high exposure against permanent deformation. The difference in a decrement of stiffness in untreated WCO mixture was noticeable as the stiffness was drastically decreased from the control mixture. In contrast, as the stiffness in treated WCO mixture was slightly lower than the control mixture, not much difference in decrement between the mixtures was therefore presented.

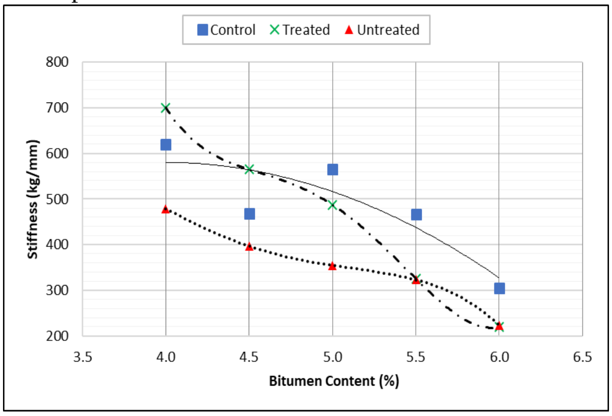

Fig 3 The stiffness of asphaltic concrete containing untreated and treated WCO

IV. CONCLUSIONS

a) The hot mix asphalt incorporating treated WCO exhibited the highest stability followed by a control mixture while the lowest stability recorded by untreated WCO mixture. High stability depicted high adhesiveness potential of bitumen that can hold and bind the aggregate efficiently.

b) The lowest flow was verified by treated WCO mixture where untreated WCO mixture was higher than the control mixture. This indicated a low deformation rate, and it was expected to have high resistance to rutting.

c) The stiffness property was affected by the highest stability with the lowest flow performance. Treated WCO achieved the highest stiffness. The lowest stiffness achieved by untreated WCO mixture interpreted the high potential of permanent deformation to occur due to the low rutting resistance.

ACKNOWLEDGMENT

The support provided by the Malaysian Ministry of Higher Education and Universiti Malaysia Pahang in the form of a research grant (RDU/UMP) vote number RDU1803160 for this study is highly appreciated.

REFERENCES

1. A. A. Hussein, R.P. Jaya, N.A. Hassan, H. Yaacob, G.F. Huseien and M.H.W. Ibrahim, "Performance of nanoceramic powder on the chemical and physical properties of bitumen," *Construction and Building Materials*, 156, 2017, 496-505.
2. W. N. A. Azahar, R.P. Jaya, M.R. Hainin, M. Bujang and N. Ngadi, 'Chemical modification of waste cooking oil to improve the physical and rheological properties of asphalt binder," *Construction and Building Materials,* 126, 2016, 218-226.
3. S. N. A. Jeffry, R. P. Jaya, N. Abdul Hassan, H. Yaacob, J. Mirza, and S. H. Drahman, "Effects of nanocharcoal coconut-shell ash on the physical and rheological properties of bitumen," *Constr. Build. Mater*., vol. 158, 2018, pp. 1–10.
4. N. Manap, R. Putra Jaya, S. N. A. Jeffry, N. A. Miron, N. Abdul Hassan, M. R. Hainin, and C. N. C.W., "The effect of coconut shell on engineering properties of porous asphalt mixture," *Jurnal Teknologi*, 78, no. 7–2, 2017, pp. 127–132.
5. H. Wen, S. Bhusal and B. Wen, "Laboratory Evaluation of Waste Cooking Oil-Based Bioasphalt as an Alternative Binder for Hot Mix Asphalt.," *Journal of Materials in Civil Engineering*, 25(10), 2013, 1432–1437.
6. S. Chebil, A. Chaala and C. Roy, "Use of Softwood Bark Charcoal as a Modifier for Road Bitumen," *Fuel*, 79, 2000, 671-683.
7. R. Maharaj, V. R. Harry and N. Mohamed, "Rutting and Fatigue Cracking Resistance of Waste Cooking Oil Modified Trinidad Asphaltic Materials" *The Scientific World Journal*, 2015, 1-7.
8. P. Teymourpour, S. Sillamäe and H. U. Bahia, "Impacts of Lubricating Oils on Rheology and Chemical Compatibility of Asphalt Binders," *Road Materials and Pavement Design*, 16, 2015, 50-74.
9. Jabatan Kerja Raya (JKR), "Standard Specification for Road Works." pp. S4–58–S4–69, 2008.
10. ASTM D6927. 2015. Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures. ASTM International, West Conshohocken, PA, USA.
11. N. M. Katamine, Physical and Mechanical Properties of Bituminous Mixtures Containing Oil Shales. *Journal of Transportation Engineering*, 126(2), 2000, 178-184.
12. M. N. Borhan, F. Suja, A. Ismail and R. A. O. K. Rahmat, "The Effects of Used Cylinder Oil on Asphalt Mixes," *European Journal of Scientific Research*, 28(3), 2009, 398-411.